The 2018 EXPORTS Pacific Experiment

Calibration of the CTDs on Lagrangian Float #92

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Summary

Temperature, salinity and pressure sensors on the top and bottom of the EXPORTS Lagrangian float (#92) spanning 16 August 2018 to 01 December 2018 were adjusted to be self-consistent, true to float geometry, and consistent with CTD data from the *R/V Sally Ride* and *CCGS Tully* CTD. Pressure difference between the two sensors depends on pressure and the vertical speed of the float through the water. Removing these, the relative accuracy is a few centimeters equivalent; the absolute accuracy is about 0.3 dbar mostly due to atmospheric pressure variations. Temperature and salinity are offset to be consistent with 6 calibration casts taken within 1 km and 30 minutes of a float profile. After adjustment, temperature is accurate to ±0.002 C, salinity to ±0.002 psu between the sensors and ±0.01 psu absolute. There is no evidence for drifts larger than these limits. The data is released in two SEABASS files
EXPORTS-EXPORTSNP_bottomCTD_float_20180414_R11.sb
EXPORTS-EXPORTSNP_topCTD_float_20180414_R11.sb

1. Sensors & Mission

Float 92 was the only Lagrangian float deployed in EXPORTS 2018. It carried SBE-41-CT sensors on the top (SN CT-10503, Fig 1a) and bottom (SN CT-10502, Fig. 1b) endcaps with the entrances to the sensors separated vertically by 1.69 m. The top CTD included a Seabird SBE-63 Optode. The output of the bottom CTD was pumped through a SUNA nitrate sensor. Pressure was measured with sensors attached to the inside of the top and bottom endcaps, separated vertically by ~1.15 m.

Float 92 was deployed on 14-Aug-2018 07:15Z from the *R/V Sally Ride*, sampled for 109.3 days with the last data taken on 01-Dec-2018 14:34 Z. The float was recovered shortly thereafter by *R/V Sikuliaq*. Each CTD sampled 101661 data points, with an average separation of ~93 seconds. The float also successfully measured nitrate, oxygen, optical backscatter and chlorophyll fluorescence. The accuracies of these sensors are described in other data reports.

Calibration casts were made from the *R/V Revelle* and *R/V Sally Ride* during the main experimental period, from the *CCGS Tully*, in late September and from the *R/V Sikuliaq* at recovery. Cast times are listed on plots in Appendix A. Additional information on ship CTD casts is available in EXPORTS ship data reports.

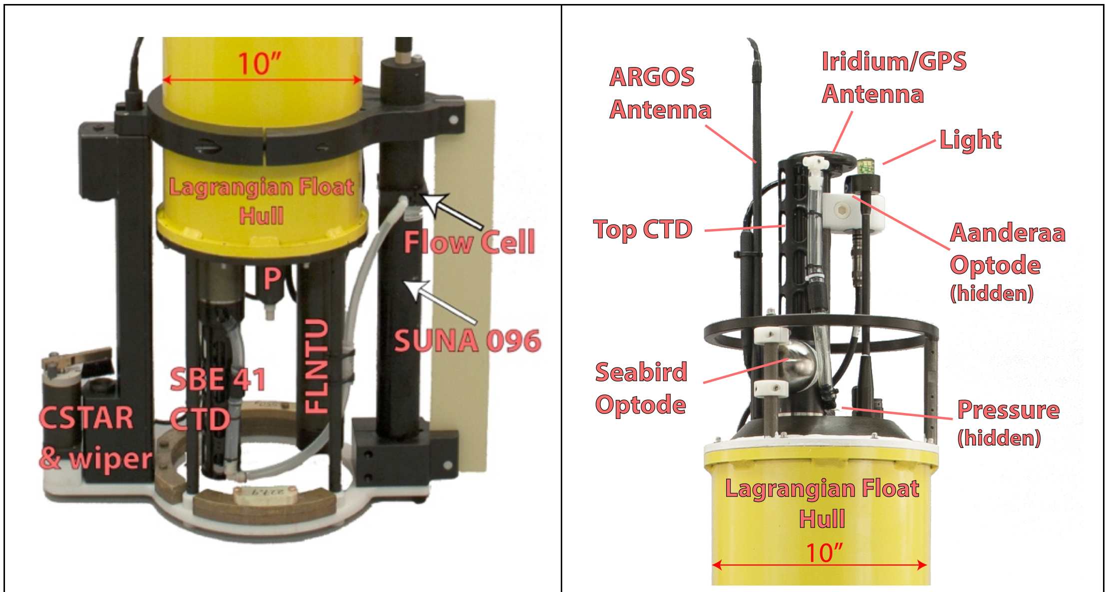


Figure 1. Sensors at a) bottom and b) top of EXPORTS float 92. A flag was attached to the top, endcap but not shown here.

The float executed a simple mission (Fig. 2) alternating between daily profiles to 200m and a Lagrangian drift at approximately 100 m. More precisely, during the drift the float targeted the 25.85 kg m^{-3} isopycnal maintaining this isopycnal between the top and bottom CTDs as it moved vertically ±10m due to internal waves and tides and mesoscale eddies (Fig. 3). Profiles occurred once per day, timed to approximating 0130Z during the cruises so as to facilitate calibration casts, and to approximately 1300Z thereafter, so as to facilitate nighttime air calibrations of the oxygen probe.

The CTD sensors on the float were sampled every 100s during the drift and 15-75s during profiles depending on other activities. Other sensors were sampled less frequently, mostly to save energy.

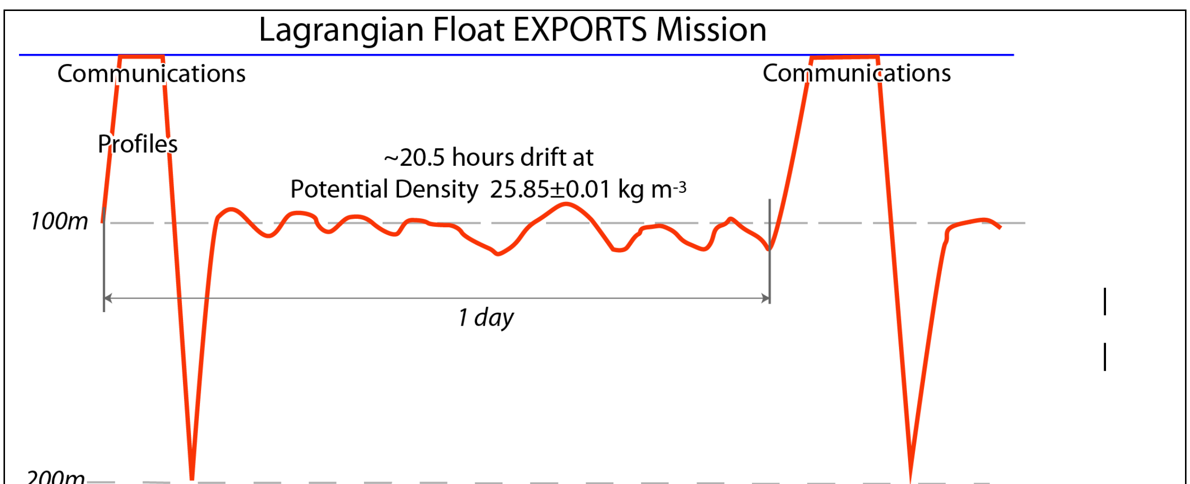


Fig. 2. Float mission. Float alternated between daily profiles from 200m to the surface and a Lagrangian drift at approximately 100m.

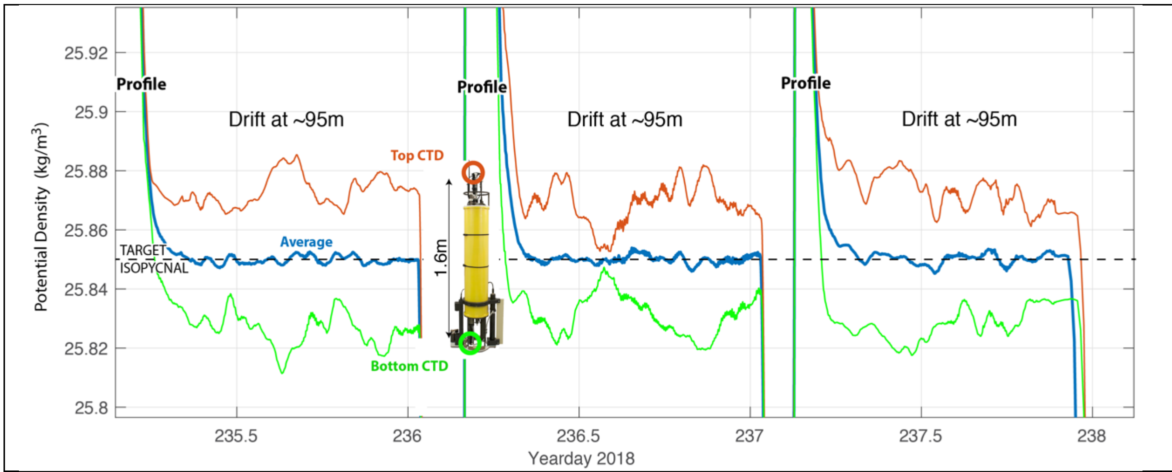


Fig. 3. Example of isopycnal drift. Float straddles target isopycnal with an accuracy of about 0.1 m.

2. Pressure calibration

Relative calibration- The pressure difference between the two sensors varies by up to ~1.5 dbar due to the combined effect of pressure and vertical velocity (Fig. 4a).

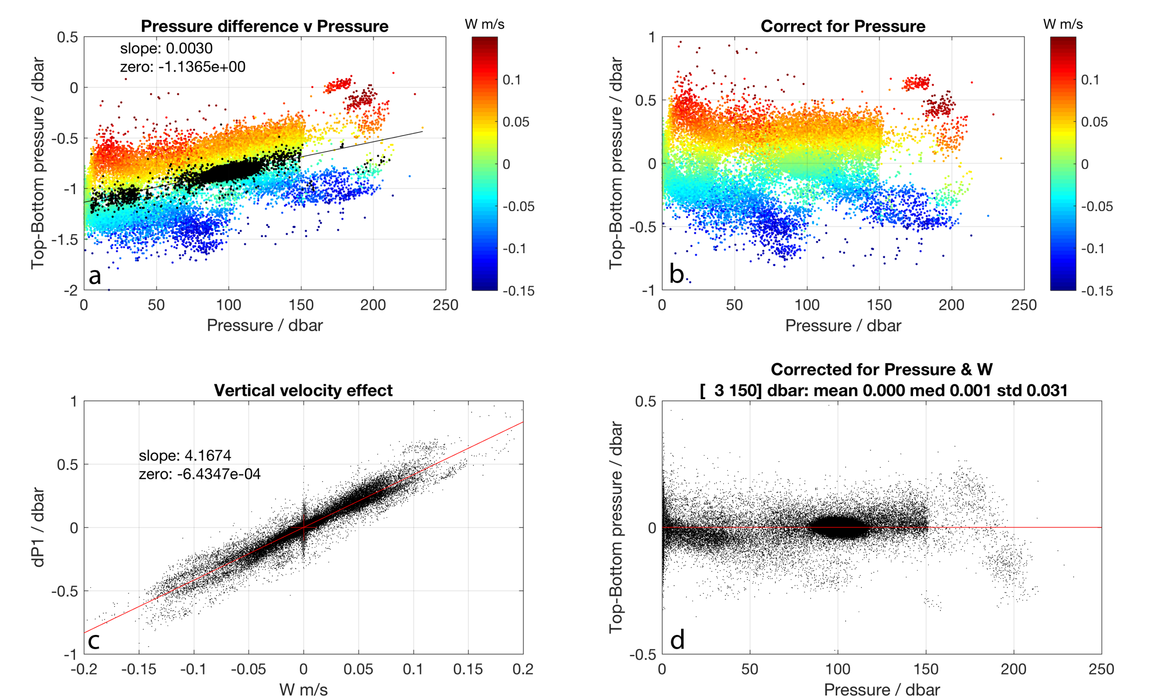


Figure 4. Pressure difference between top and bottom sensors. a) Pressure difference v. average pressure colored by vertical velocity. Black dots show data with small vertical velocities; black line is fit to them. b) Pressure effect removed, colored by vertical velocity. c) Residual from (b) against vertical velocity; red line is fit. d) Residual difference after pressure and velocity effects have been removed.

Removing the pressure effect (black line in Fig. 4a) reduces the variation to about 1 dbar maximum, which linearly depends on vertical velocity (Fig. 4c). Removing both (Fig. 4d) reduces the variation to about 0.03 dbar, comparable to the calibration variation.

The pressure effect, about 0.3%, somewhat more than twice the specified 0.1% initial accuracy, is plausibly due to differences in the calibration between the two sensors. The velocity effect is most likely due to the form drag on the float, which for these slow vertical velocities, is nearly linear and due to stratification effects.

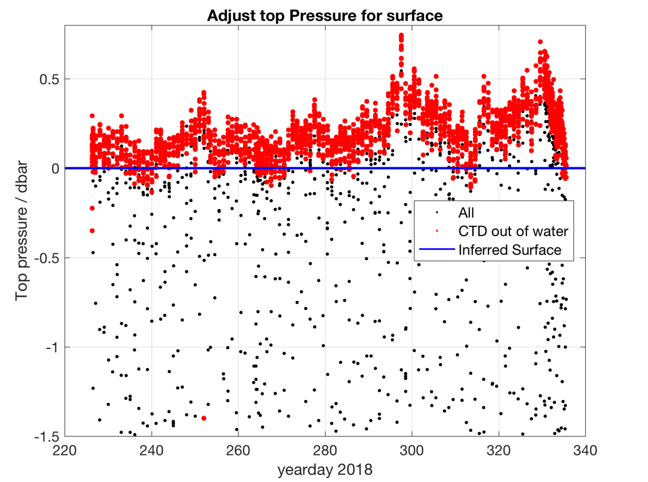


Figure 5. Near-surface values of top pressure sensor. Red points show salinities from top CTD less than 32 psu and thus out of the water. Pressures are adjusted so to place this at zero pressure, thus zeroing the pressures to the surface pressure.

Surface Offset - These effects are removed, and pressures adjusted so their difference is the distance between the top and bottom CTD intakes. Pressure is referenced to the ocean surface by noting that the salinity measured by the top CTD dramatically drops when the CTD breaks the surface. Figure 5, shows the top pressure very close to the surface. Values where the top salinity is less than 32 psu are colored red, marking the surface. The pressure is adjusted so this is close to zero. Variations in this boundary of up to 0.3 dbar, probably due to atmospheric pressure variations, are evident.

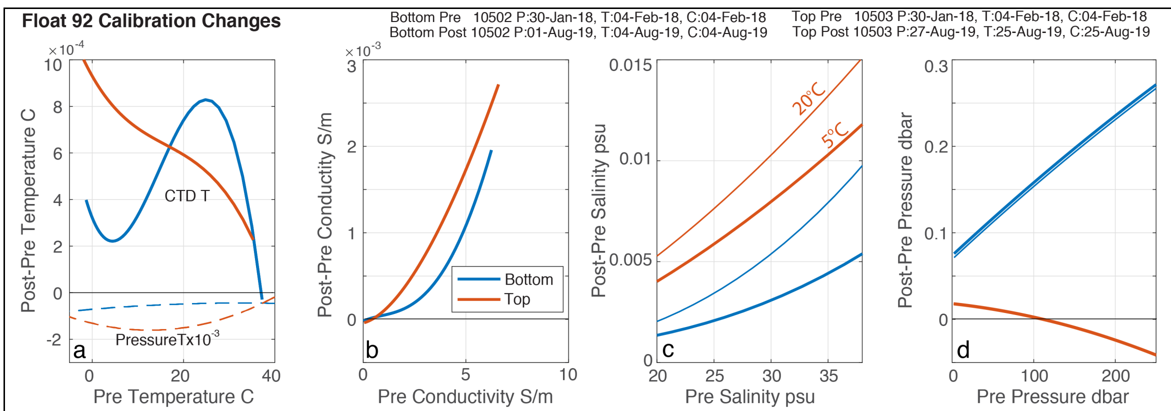


Fig. 6. Seabird calibrations before (Feb 2018) and after (August 2019) deployment. Each panel plots difference between computed scientific values using pre and post deployment calibrations for a) temperature, b) conductivity, c) Salinity at 20C (thin) and 5C (thick) and d) Pressure at 20C (thin) and 5C (thick). Blue lines are bottom CTD, Red are top CTD. Calibration dates are listed in top header.

With these adjustments, the two pressures correspond to the pressures at the top and bottom CTD intakes referenced to the surface. The relative accuracy is a few centimeters equivalent; the absolute accuracy is about 0.3 dbar mostly due to atmospheric pressure variations. These could be removed to provide higher accuracy if needed.

Seabird Calibrations- The CTD sensors were calibrated at Seabird in February 2018 and August 2019, 17 months apart. Fig. 6 plots the difference between these calibrations for each of the CTD output quantities. Since the CTD output data is computed using the pre-deployment calibrations, this figure indicates the change in these quantities due to shifts in sensors calibration since February 2018.

Pressure is shown in Fig. 6d. The calibrations were computed at 20C (thick line) and 5C (thin line). These are nearly indistinguishable so the temperature correction to pressure is negligible, despite the large change in the calibration of the pressure sensor thermistor (Fig. 6a, dashed). The pressure change (Fig. 6d) at zero pressure is less than 0.1 dbar for both sensors. At 250 dbar, the top sensors changes by less than 0.05 dbar, but the bottom sensor output increases by 0.3 dbar. Thus, top pressure minus bottom pressure decreases, becoming more negative with increasing pressure. This is of similar magnitude, but of the opposite sign to that shown in Fig. 4a and thus does not explain the observed difference between the two sensors.

Thus, the two Seabird calibrations provide no additional consistent guidance. No adjustments to the pressure at depth are made. The Seabird specification of 0.1% or 0.4 dbar is thus assumed, comparable to the surface zeroing accuracy.

3. Temperature and salinity calibration

Relative calibration- The top and bottom temperature and salinity sensors are intercalibrated by comparing the values in the mixed layer, here defined as pressures between 5 and 10 dbar. Figure 7 shows that the top CTD is persistently warmer than the bottom by 0.002±0.002 C and persistently saltier by about 0.002±0.001 psu. The values are more stable later in the record when the mixed layers are deeper and better mixed. The data suggest a trend in both temperature and salinity, but this is not strong enough to include in the calibration.

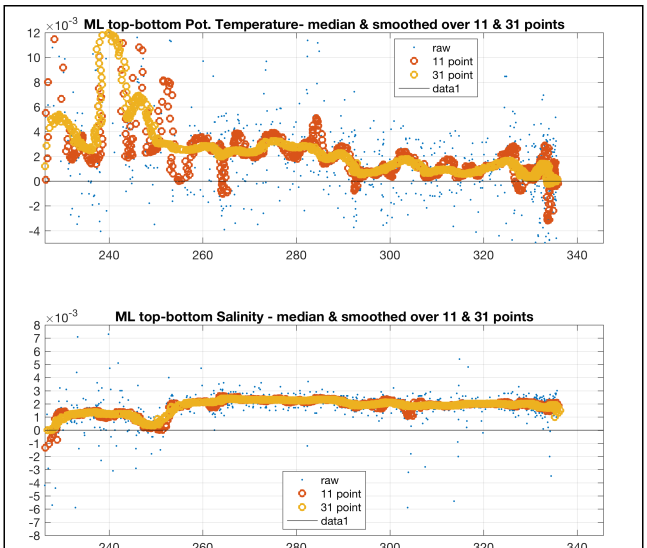


Figure 7. Difference between top and bottom CTD temperature (top) and salinity (bottom) measurements when the float pressure is between 5 and 10 dbar. Dots are data, circles are 11 and 31-point median filtered data and lines are at zero.

Thus, the top CTD sensor is made consistent with the bottom one by subtracting 0.002 C and 0.002 psu from its data. The relative sensor drift during the deployment is less than 0.002 C and 0.002 psu.

Seabird Calibrations- Figure 6a shows the shift in temperature between the two calibrations. The changes are less than 0.001C at all temperatures. This is consistent with Seabird's drift specifications and indicates that no trend in temperature should be added to the calibration.

Figure 6c shows the shift in salinity between the two calibrations. The salinity values increase with the top sensor increasing more than the bottom one, with a difference of about 0.005 psu in the EXPORTS temperature and salinity range. This is consistent with Fig. 7 showing higher values of the top Salinity in the mixed layer.

Absolute calibration- The float CTD data is further adjusted for consistency with the 'Gold standard' CTD on the *R.V. Sally Ride* using the 5 calibration casts made close to the float. The EXPORTS "HydroTeam Preliminary Data" dated March 6, 2019

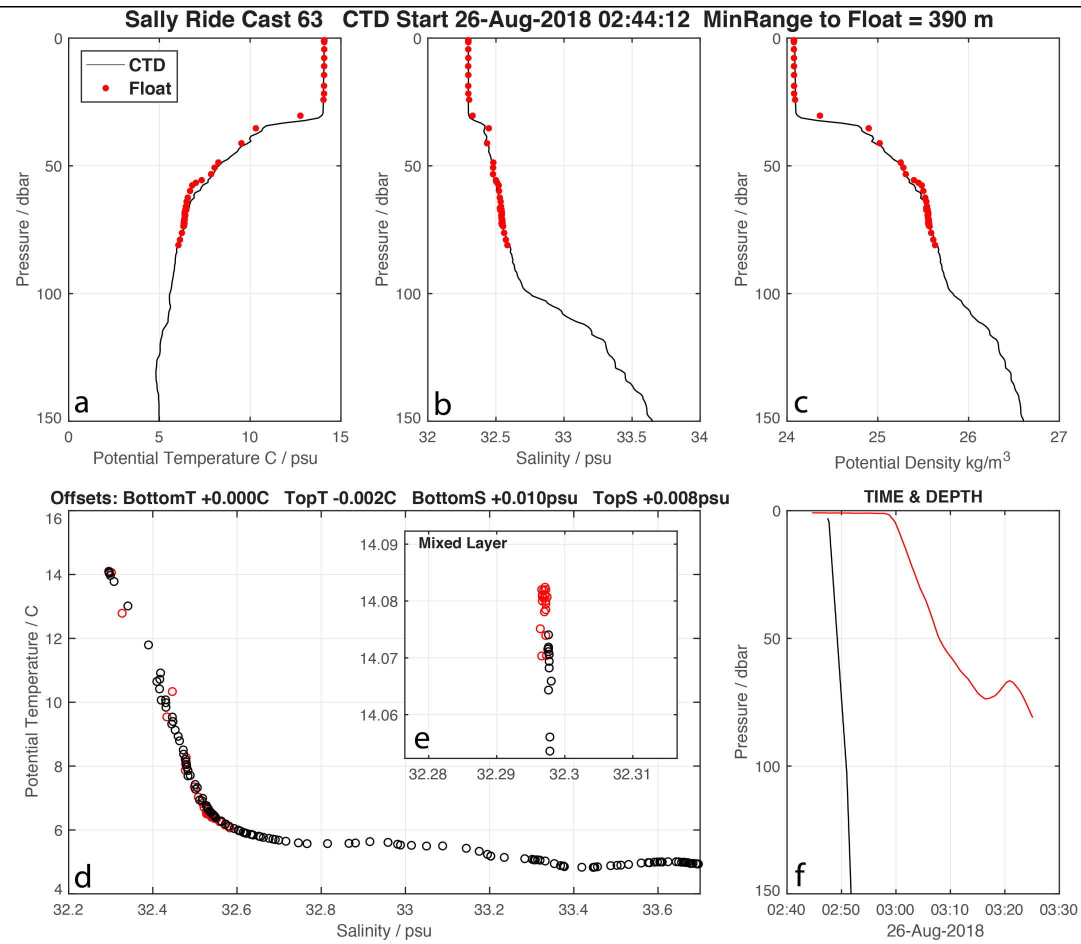


Figure 8. Comparison of CTD data from float (red) and 1-m binned Sally Ride calibration cast 63 (black) Float data has been adjusted as listed in the figure. a) Potential temperature profiles, b) salinity profiles and c) potential density profiles. Potential temperature/salinity plots for the d) entire profile and e) the mixed layer. f) Depth-time profiles for the casts.

(duplicated September 16, 2019), "Binned 1-m" data is used. Additional calibration casts from *CCGS Tully* cruise 2018-040, cruise event 96 and *R/V Sikuliaq* cruise 2018-22 CTD 3 are also used.

A typical calibration cast (Figure 8) was made within a few hundred meters and a few 10's of minutes of a float profile. Despite this close distance, only the mixed layer is homogeneous enough to make quality comparisons. Similar plots for all calibration casts are shown in Appendix A.

Mixed layer values from all calibration casts show float salinities (Fig. 9b) to be about 0.01 psu lower than the *R/V Sally Ride* salinities. The float salinities will thus be adjusted by this offset.

Differences in temperature are large, order ±0.01 C, and of both signs. This is much larger (~0.01C) than the expected errors in temperature (Fig. 6a) of less than ±0.001C. Thus, the mixed layer is not sufficiently homogeneous in temperature to intercalibrate the temperature sensors.

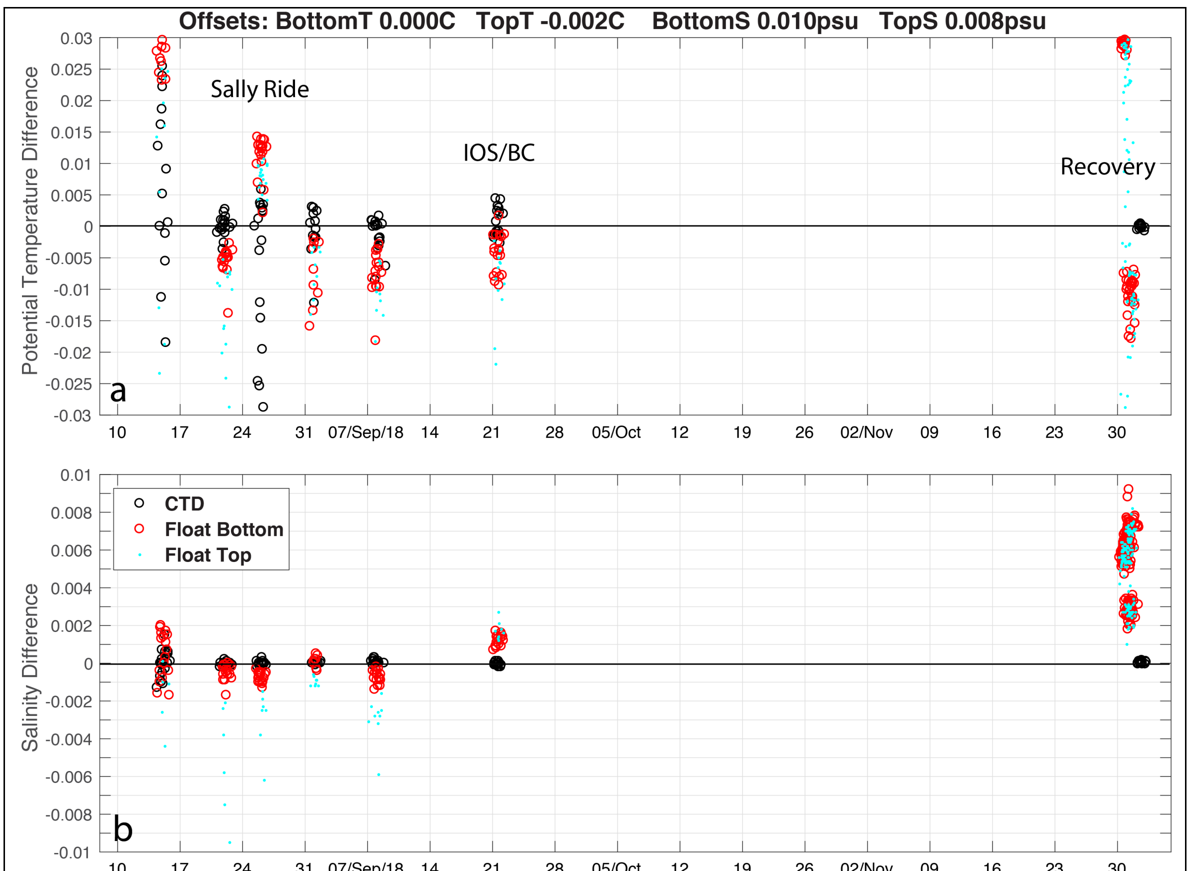


Figure 9. a) Potential temperature and b) salinity from mixed layer (pressure <20 dbar) for ship CTD calibration casts (black) and nearby bottom (red) and top (blue) float CTD sensors. Plots for all comparisons are in Appendix A. Median values from ship data for each cast is subtracted. Offsets in header have been subtracted from float data; this figure shows the calibrated float data.

The calibration cast from *CCGS Tully* is consistent with the *R/V Sally Ride* data. The cast from the *R/V Sikuliaq* shows differences up to 0.01 psu. However, this was made roughly 1 day after the last float data so that these differences could be due to temporal variability. Based on the Seabird calibrations, the change should be less than 0.015 psu. The smaller value is chosen.

5. Summary

Data from the pair of temperature, salinity and pressure sensors on the top and bottom of the EXPORTS Lagrangian float was adjusted to be self-consistent, true to float geometry, and consistent with data from the *R/V Sally Ride* CTD during the 2018 EXPORTS field campaign. The adjusted data is released two SEABASS files

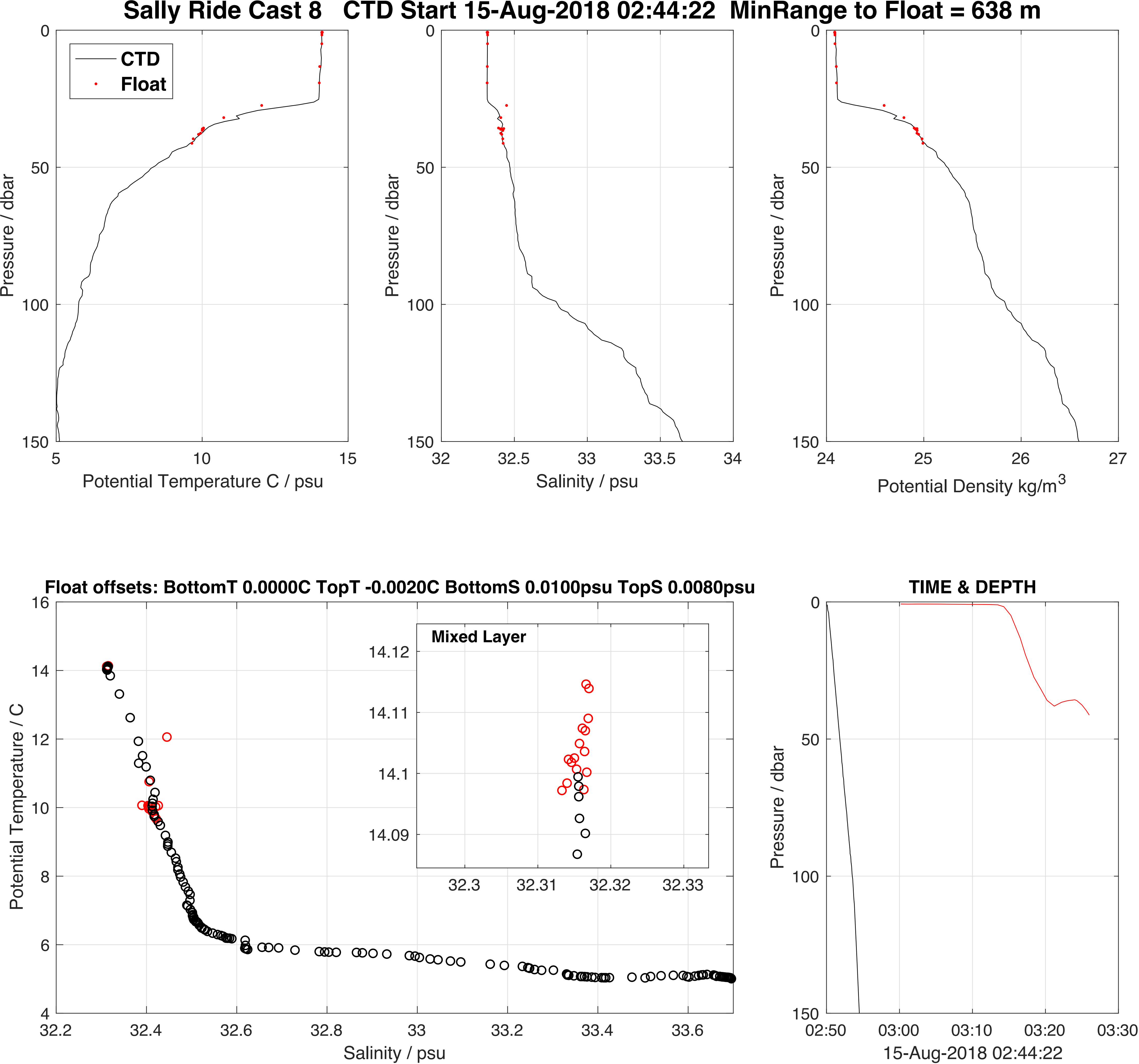
EXPORTS-EXPORTSNP_bottomCTD_float_20180414_R11.sb
EXPORTS-EXPORTSNP_topCTD_float_20180414_R11.sb

Scans with negative pressure or unknown positions have been deleted.
A matlab version is also available from the author.

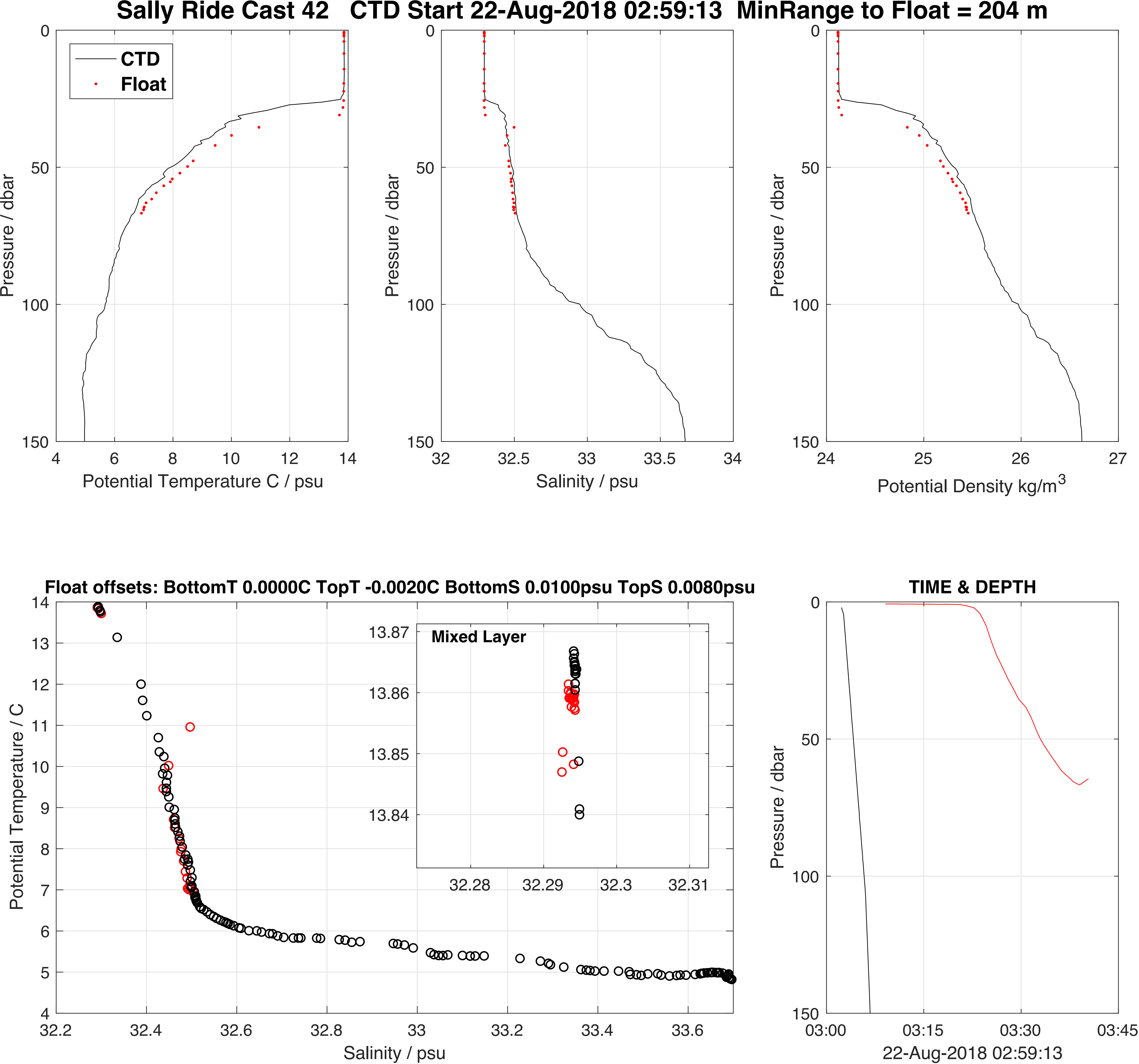
All variables are on the same timebase.

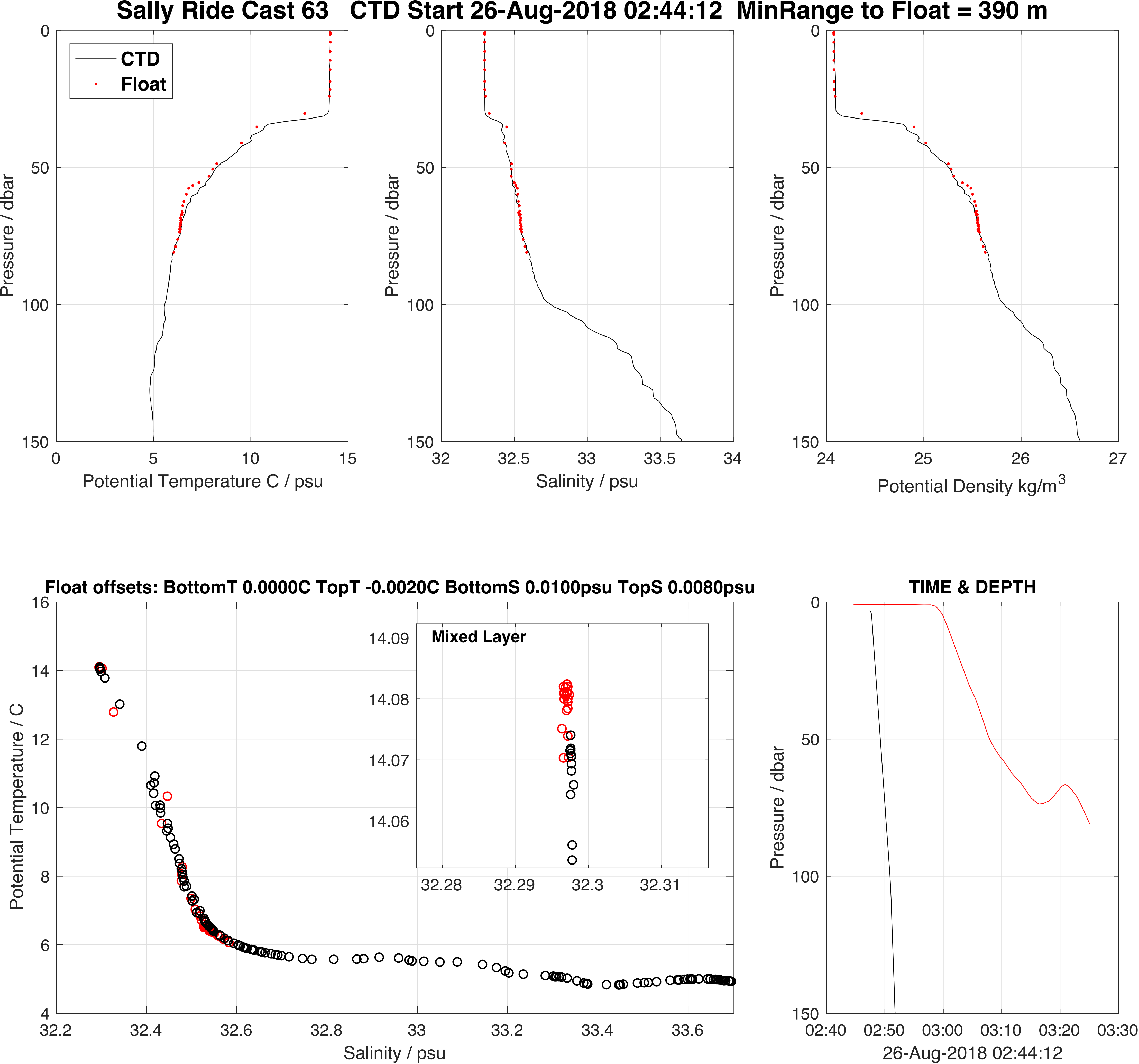
Name	**Description**	**Accuracy**
Time and date	From GPS	1 sec
lat, lon	Position interpolated from GPS fix	10m at GPS fix time.
T	Temperature ITS-90 degrees C at bottom top CTD intakes	±0.002 C
S	Practical salinity EOS-80 psu at bottom and top CTD intakes	±0.002 psu between sensors ±0.01 psu absolute
PP	Pressure dbar relative to sea surface at bottom top PP(:,2) CTD intakes	Relative difference is fixed. ±0.4 dbar absolute

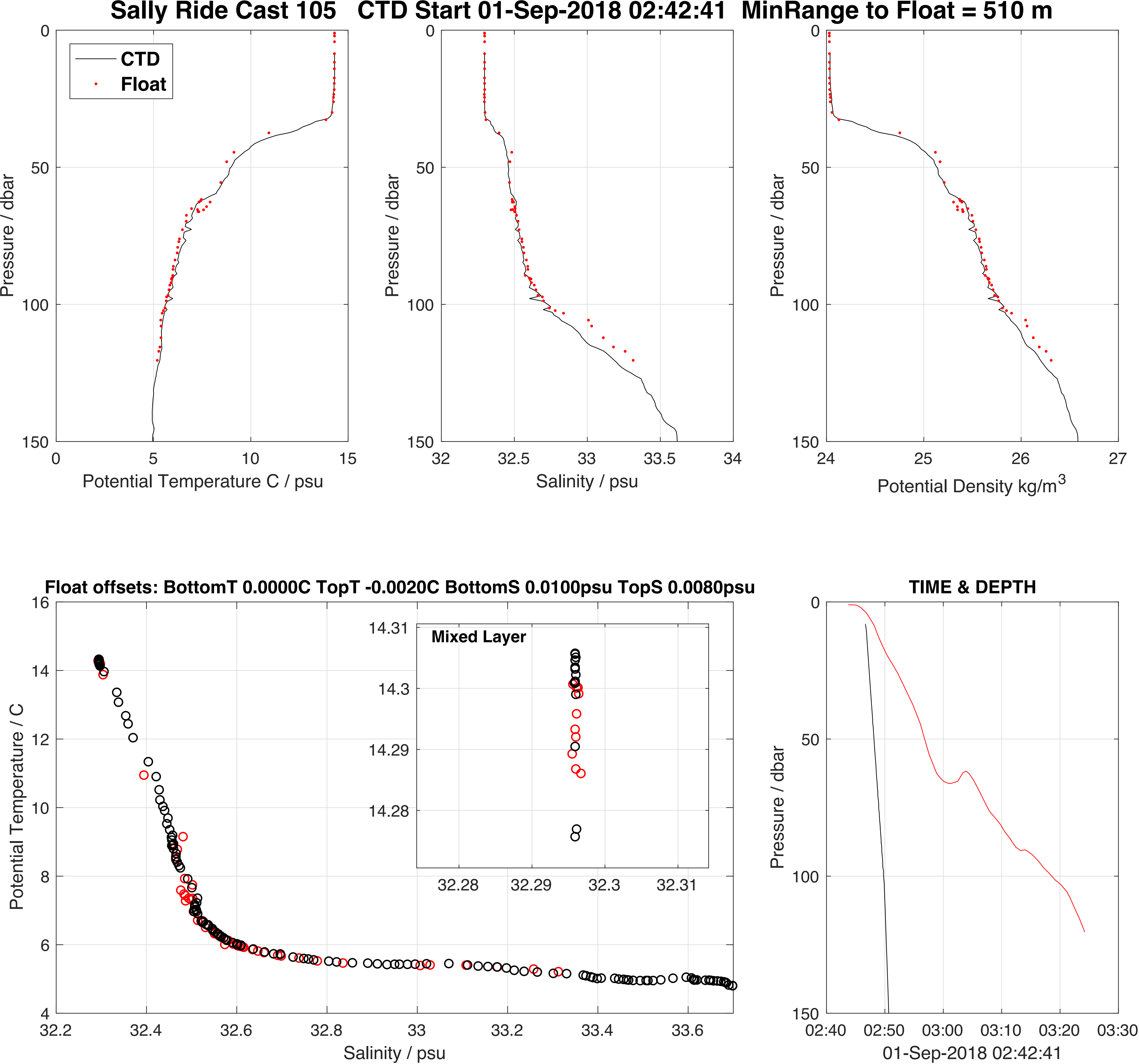
APPENDIX A - Calibration Casts



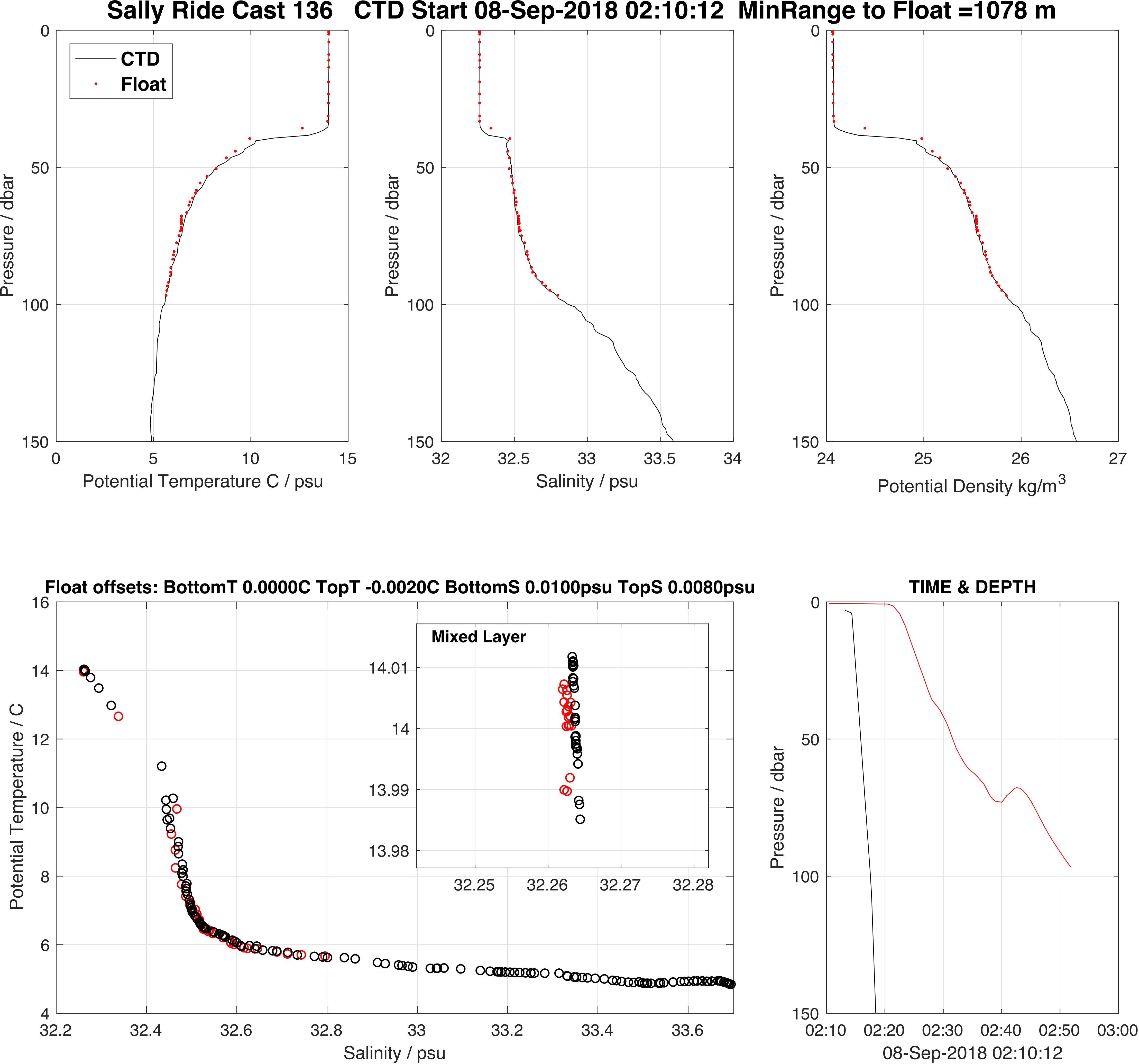
Sally Ride Cast 8   CTD Start 15-Aug-2018 02:44:22 MinRange to Float = 638 m
CTD
Float
Pressure / dbar
Potential Temperature C / psu
Salinity / psu
Potential Density kg/m^3
Float offsets: BottomT 0.0000C TopT -0.0020C BottomS 0.0100psu TopS 0.0080psu
Mixed Layer
Potential Temperature / C
TIME & DEPTH
15-Aug-2018 02:44:22


Sally Ride Cast 42   CTD Start 22-Aug-2018 02:59:13   MinRange to Float = 204 m
CTD
Float
Pressure / dbar
Potential Temperature C / psu
Salinity / psu
Potential Density kg/m3
Float offsets: BottomT 0.0000C TopT -0.0020C BottomS 0.0100psu TopS 0.0080psu
Mixed Layer
Potential Temperature / C
TIME & DEPTH
22-Aug-2018 02:59:13

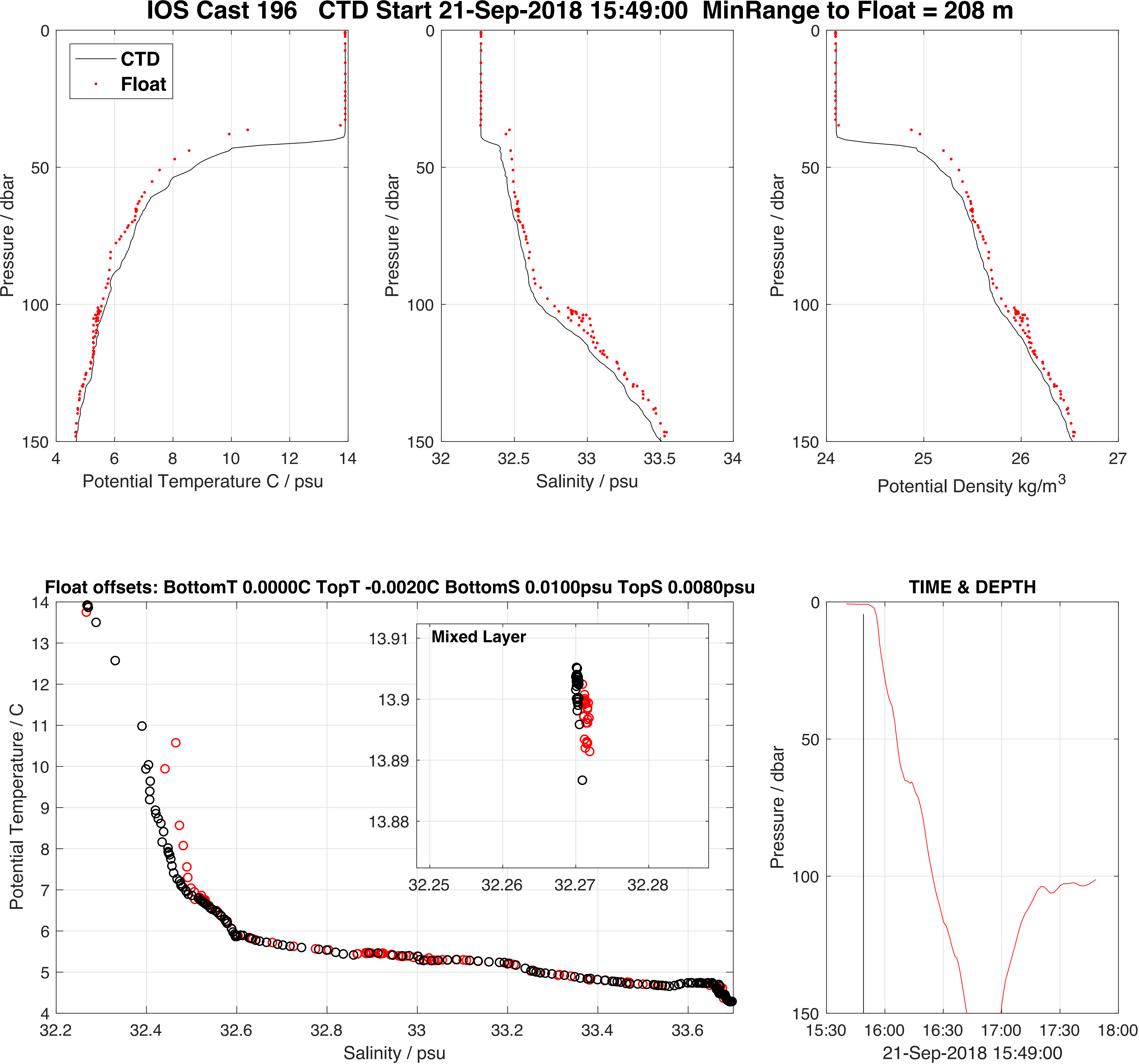

Sally Ride Cast 63   CTD Start 26-Aug-2018 02:44:12   MinRange to Float = 390 m
CTD
Float
Pressure / dbar
Potential Temperature C / psu
Salinity / psu
Potential Density kg/m^3
Float offsets: BottomT 0.0000C TopT -0.0020C BottomS 0.0100psu TopS 0.0080psu
Mixed Layer
Potential Temperature / C
TIME & DEPTH
26-Aug-2018 02:44:12



Sally Ride Cast 105 CTD Start 01-Sep-2018 02:42:41 MinRange to Float = 510 m
CTD
Float
Pressure / dbar
Potential Temperature C / psu
Salinity / psu
Potential Density kg/m^3
Float offsets: BottomT 0.0000C TopT -0.0020C BottomS 0.0100psu TopS 0.0080psu
Mixed Layer
Potential Temperature / C
TIME & DEPTH
01-Sep-2018 02:42:41



Sally Ride Cast 136 CTD Start 08-Sep-2018 02:10:12 MinRange to Float =1078 m
CTD
Float
Pressure / dbar
Potential Temperature C / psu
Salinity / psu
Potential Density kg/m3
Float offsets: BottomT 0.0000C TopT -0.0020C BottomS 0.0100psu TopS 0.0080psu
Potential Temperature / C
Mixed Layer
TIME & DEPTH
08-Sep-2018 02:10:12



IOS Cast 196 CTD Start 21-Sep-2018 15:49:00 MinRange to Float = 208 m
CTD
Float
Pressure / dbar
Potential Temperature C / psu
Salinity / psu
Potential Density kg/m3
Float offsets: BottomT 0.0000C TopT -0.0020C BottomS 0.0100psu TopS 0.0080psu
Mixed Layer
Potential Temperature / C
TIME & DEPTH
21-Sep-2018 15:49:00

Recovery Cast 503   CTD Start 02-Dec-2018 16:09:17 MinRange to Float =1284 m